A Climatological Analysis of the Weather Distribution in Tohoku District in Winter

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Hiroshi SHITARA

Introduction

The climate of Japan is influenced by the monsoon, especially in winter, when the northwest wind as the polar air current from the excessively high pressure area of Siberia into the Aleutian low pressure area, prevails over and around Japan. Since the cyclones developing in the Pacific polar frontal zone pass along the east coast of Asia to the northeast, the polar air out-breaks behined cyclones. In the season, therefore, the current from Siberia is not stationary, but the period of violent blow and that of seasing appear alternately. A cold, dry, continental polar air from Siberia is much modified over the Japan Sea, and becomes warm, moist and unstable after passing the Japan Sea.

As the Islands of Japan lie athwart the air-stream, the Japan Sea side of the Islands is exposed to it, and the Pacific side is sheltered by the relief of mountains. In winter it snows frequently on the former wind-ward side, but it is usually dry, sunny and fine on the latter leeside. The contrast is shown in Fig. 1 with the example of sunshine.

It is the contrast concerning the weather in winter that characterizes the climate of the Pacific side and Japan Sea side. They are called the climate of "the Pacific side type" and that of "the Japan Sea side type". The climate of the mainland of Japan is classified into these two types of climate by many climatologists.

In the previous studies, the boundary line between the two regions of climatic types has been drawn along the backbone range based on the distribution of winter precipitation. However, there are heavy snowfalls in this backbone range area, and they gradually decrease on the eastern slope, so the boundary lines drawn by the investigators are not definite. In order to avoid such uncertain division, daily weather distributions in winter have been investigated, and the location where weather divides appear most frequently has been studied. Such climatic divisions based on the weather divides have been attempted in the scale of whole Japan,[1)-4)] and in meso-scale of detailed local investigations.[5)-8)]

In this paper, the detailed local investigations will be attempted in Tohoku

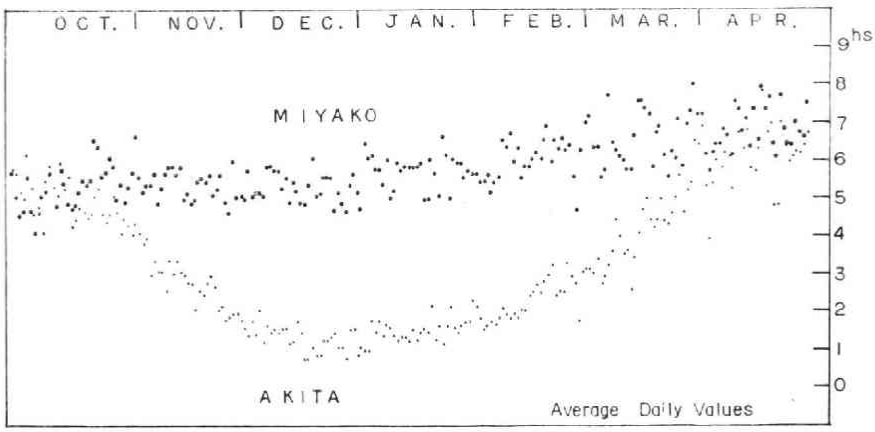


Fig. 1. Contrast of sunshine between the Pacific coast and the Japan Sea coast.

District to establish the regional division in meso-scale from the view-point of the regional characteristics of weather appearance, which is the most important element to determine the distribution pattern of climate, especially in Tohoku District.

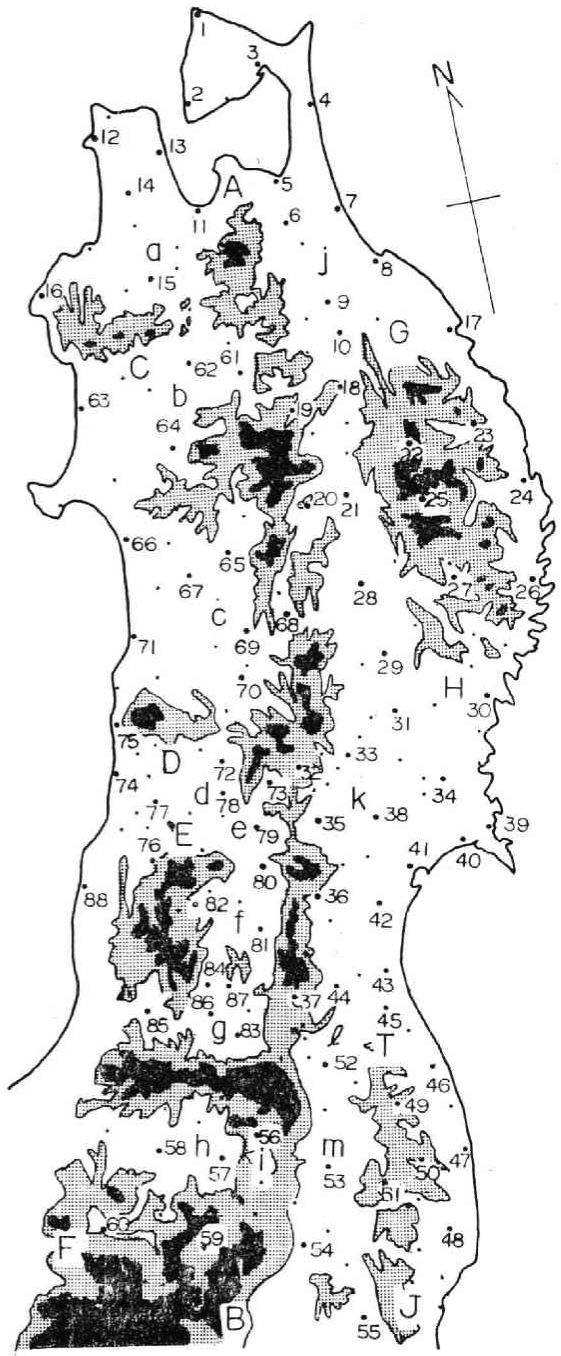
This study is based on the data of weather observed at about 200 stations at 10 h, a, m. in January, 1945 to 1947.

I Geographical distribution of appearance frequency of the weather

The topography of Tohoku District is very complicated as shown in Fig. 2. The Ou mountains (A-B) as the backbone range run through the District north to south, dividing it into the Pacific side and the Japan Sea side. On the Japan Sea side, the Dewa hills (C-D) and the Echigo mountains (E-F) run north to south parallel with the backbone range, making may basins (a~h) between them. On the Pacific side, the Kitakami mountains (G-H) and Abukuma mountains (T-J) run parallel with the backbone range. According to the land feature, weather distribution shows complicated pattern in Tohoku District.

1) *Appearance frequency of weather under the typical winter-type pressure distribution*

The characteristics of weather distribution in winter conspicuously appear on the days of typical winter-type pressure distribution, high to the west and low to the east. Fig. 3 shows the distribution of number of snowy days out of 28 exmaples with such a pressure pattern, and Fig. 4 shows the distribution of snowy or cloudy days out of the same examples. Both figures show the pattern that high frequency areas of such weather are generally limitted at the high mountains but



5 Noheji
8 Hachinohe
11 Aomori
15 Hirosaki
18 Okunakayama
21 Morioka
24 Miyako
28 Hanamaki
29 Mizusawa
31 Ichinoseki
40 Ishinomaki
42 Sendai
48 Taira
52 Fukushima
53 Koriyama
54 Shirakawa
56 Inawashiro
57 Wakamatsu
62 Odate
63 Noshiro
66 Akita
69 Yokote
74 Sakata
78 Shinjo
79 Obanazawa
80 Tateoka
81 Yamagata
83 Yonezawa

A-B Ou mountains (backbone range)
C-D Dewa hills
E-F Echigo mountains
G-H Kitakami mountains
T-J Abukuma mountains
a Hirosaki basin
b Odate basin
c Yokote basin
d Shinjo basin
e Obanazawa basin
f Yamagata basin
g Yonezawa basin
h Aizi basin
i Inawashiro basin
j Sambongi plain
k Senpoku plain
l Fukushima basin
m Koriyama basin

Fig. 2. Index map

Fig. 3. Fig. 4.

Fig. 3 Distribution of mumber of snowy days in the typical winter pattern of pressure distribution

Fig. 4 Distribution of snowy or cloudy days in the typical winter type pattern of pressure distribution

protrude through the valleys or the lowered parts in the mountains. The characteristic of that pattern is more remarkable in Fig. 3 than in Fig. 4 They suggest that the mountain relief is more influential in snowy weather distribution than in cloudy weather.

In both figures, it is common that the frequency is high on the western side of the backbone range and low on the eastern side. However, the maximum frequency appears in the coastal region along the Japan Sea in Fig. 4 and in the inland region between the coastal region and the Ou mountains in Fig. 3. This means that the factor bringing snow is different from that causing cloudy weather to appear.

Fig. 5. Fig. 6.

Fig. 5 Distribution of appearance frequency of snowy weather in the gentle gradient pattern of pressure

Fig. 6 Distribution of appearance frequency of snowy or cloudy weather in the gentle gradient pattern of pressure

2) *The relation between weather distribution and pressure gradient*

The 28 examples are grouped into two, a group with comparatively steep gradient in pressure distribution pattern and a group with rather gentle gradient. The appearance frequency of "snowy or cloudy" weather is higher in the former group than in the latter. Comparatively large difference between the two kinds of frequency appears on the Pacific side of the Ou mountains, which means that the stronger is the monsoon the more widely the snowy or cloudy weather extends toward the Pacific coast beyond the backbone range.

In the examples of gentle gradient in pressure distribution, which are rare in winter, the distribution of the appearance frequency of snowy weather (Fig. 5) and

of snowy and cloudy weather (Fig. 6) are characterized by the maldistribution of higher values along the Japan Sea. From the above mentioned, the following are summarized: i) Cloudy or snowy weather is confined to the coastal part along the Japan Sea in the case of gentle gradient in pressure distribution. ii) Under the typical winter pattern of pressure distribution snowy weather frequently appear in the inland region between the Japan Sea coast and the backbone range, and cloudy weather on the Japan Sea side of the backbone range. iii) The stronger is the monsoon, the further these weathers expand to the east.

In short, the pattern of the weather distribution is effected by the strength of the monsoon.

3) ***The relation between weather distribution and flow-pattern***

The dialy difference of weather distribution shows that the weather distribution is related not only with pressure gradient but with isobar direction, that is, flow-pattern. The relations between the flow-pattern and daily precipitation were investigated as to Hokkaido[9)10)] and for whole Japan[11)]. In this section, the weather appearance in Tohoku District will be conducted regarding the flow-pattern.

The daily flow-patterns except indistinguishable one can be classified into four patterns. Such are NW, WNW, W, and WSW patterns judging from weather-

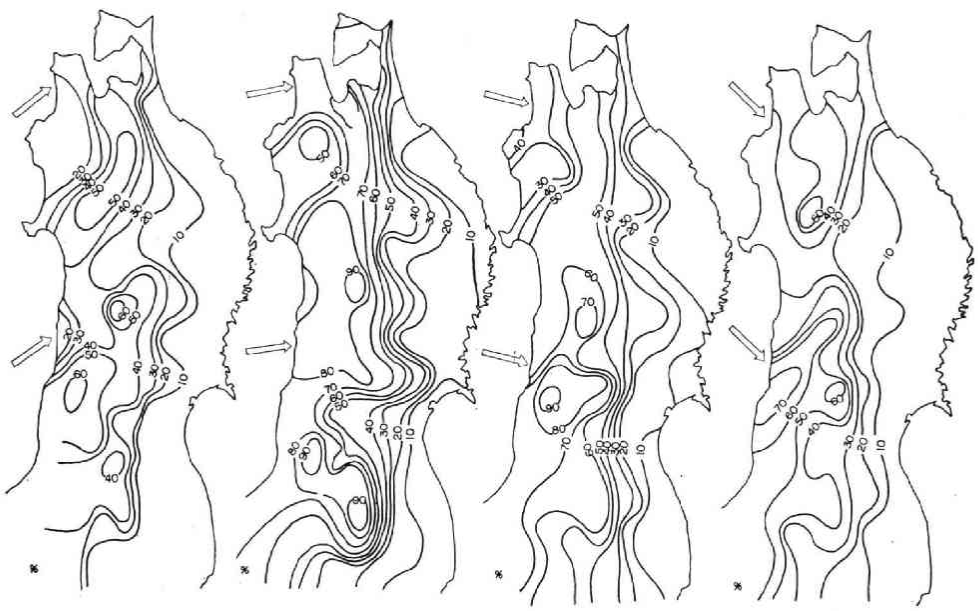


Fig. 7 Distribution of appearance frequency of snowy weather according to the direction of flow-pattern.

Fig. 8 Distribution of appearance frequency of snowy or cloudy weather according to the direction of flow-pattern

charts, and the appearance of the frequency distribution of snowy weather and of "snowy or cloudy" one according to each pattern are shown in Fig. 7 and in Fig. 8.

Comparing these four patterns of frequency distribution one another with respect to flow-pattern, the direction of flow-pattern having the highest frequency of them and that of lowest are chosen at 88 stations (for station location see Fig. 2). The former is noted in solid line and the latter in broken line in Fig. 9 in the case of snowy weather appearance, and in Fig. 10 in the case of "snowy or cloudy" weather appearance. The isopleth in both figures shows the distribution of difference between the highest value and the lowest one, at each place. These figures represent the degree of effect of the prevailing wind direction on the weather appearance, that is, the type of flow-pattern in which any weather that appears most frequently can be regionally known.

For example, the areas with the highest frequency of snow in the case of the W flow-pattern are shown in Fig. 11. In the figure, each area is confined to the funnel-like region open to the wind direction and closed leeward to the lower part of the mountains. The tendency will be understood by comparing Fig. 11 with Fig. 12 which shows another example.

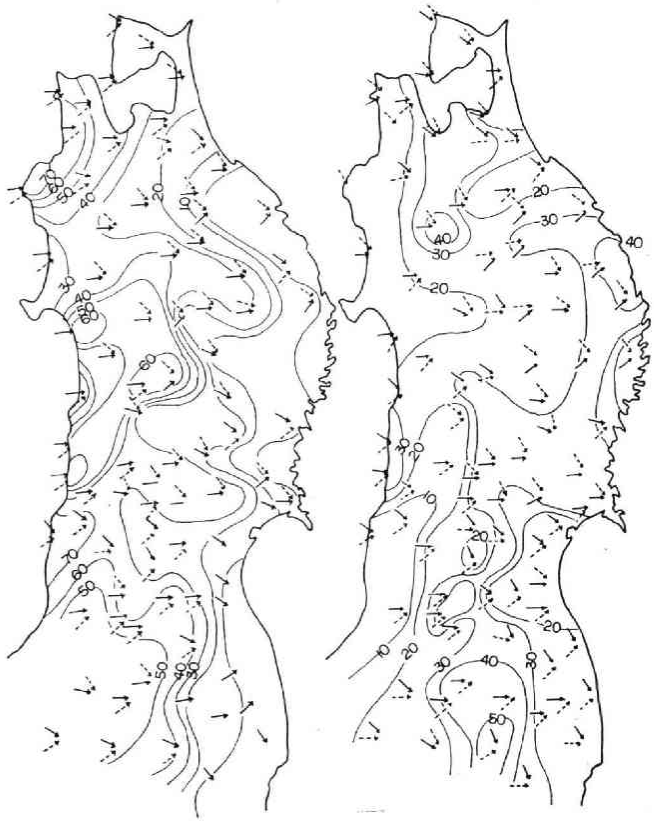


Fig. 9

Fig. 10

Fig. 9
Distribution of direction of flow-pattern with maximun (solid line) or minimum (broken line) frequency in appearance of snowy weather at each station (isopleth shows difference between the values maximum and minimum)

Fig. 10
Distribution of direction of flow-pattern with maximum or minimum frequency in appearance of snowy or cloudy weather at each station (isopleth shows difference between the values maximum and minimum)

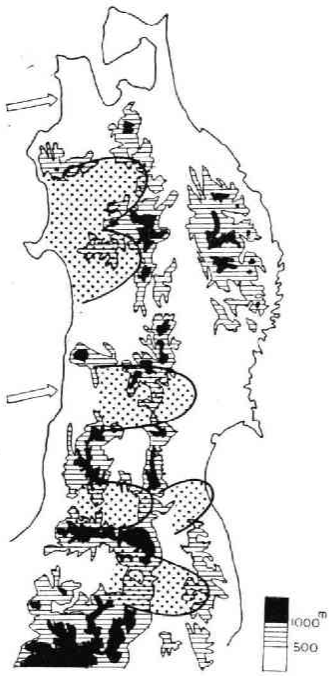


Fig. 11

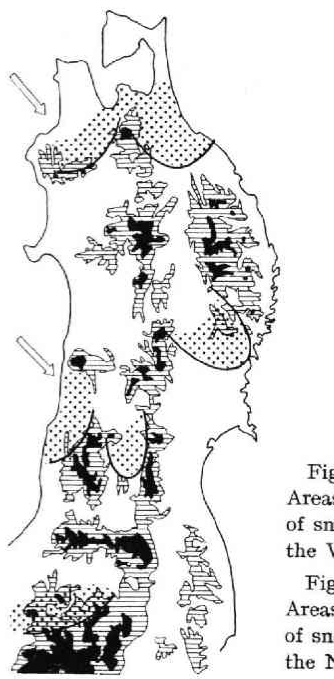


Fig. 12

Fig. 11
Areas with the highest frequency of snowy or cloudy weather in the W flow-pattern

Fig. 12
Areas with the highest frequency of snowy or cloudy weather in the NW flow-pattern

4) *Geographical expression of the combination of appearance frequency of various weather*

The appearance pattern of each weather changes day by day, effected by topography, flow-pattern and pressure-gradient, as already described above. In this section, the expression of average geographical pattern of the appearance of kinds of weather in mid-winter will be tried.

Various kinds of weather are roughly grouped into three kinds, the fine, the cloudy and the snowy. The combination of appearance frequencies of such weather in a season at any station can be expressed in a triangular diagram so that the total value of appearance frequency of these three kinds of weather may be 100%. And that combination at 88 stations in Tohoku District in January are dotted on the diagram (Fig. 13). In the diagram, it is meant that the nearer is a point to the upper pole, the higher the appearance frequency of fine weather is, and that the nearer is a point to the left pole higher is that of cloudy weather, and

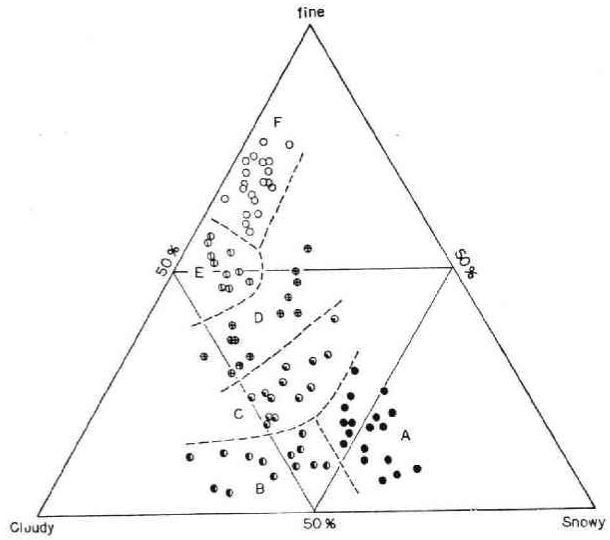


Fig. 13

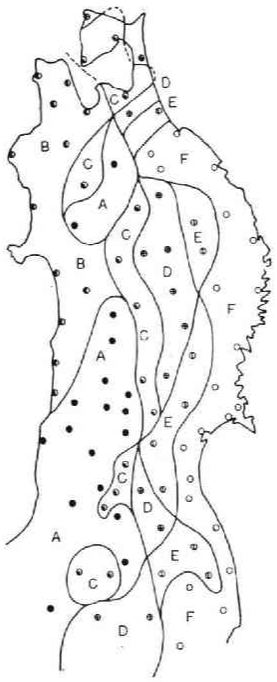


Fig. 14

Fig. 13 Triangular diagram showing fine-cloudy-snowy composition of appearnce fequency of weather at each station in Tohoku District

Fig. 14 Mapping of each point in the triangular diagram in Fig. 13

to the right pole, snowy weather.

The scattering of points in the diagram, therefore, shows the geographical variation of weather appearance in Tohoku District. These points are grouped as shown in Fig. 13, and the distribution on the geograpical map are represented in Fig. 14. Then the regional characteristics of weather appearance as average state can be known by referring to these two figures.

II The pattern of areal extent of the same weather

The pattern of weather area varies daily with the sort of weather. The fine weather areas frequently appear on the Pacific side of the Ou mountains. The weather boundary between the fine and the "cloudy or snowy" often lies along the Ou mountains, dividing Tohoku District into the east and west. The snowy weather area appears locally surrounded by the closed line in the western cloduy area. That is, the snowy area appears as a part of the cloudy area. In addition, the pattern of snowy area is variable and complciated. In this chapter the pattern of snowy area will be analyzed.

1) Areal extent of snowy weather

If a kind of weather appears throughout a region without any local variety, the number of days of such a weather is equal at any station in the region. Therefore, at every station in this given region, the probability with respect to the appearance of the same weather will become 100%.

As mentioned above, however, the snowy weather area changes from day to day, so in the field around a certain station as a base point, the probability of the appearance of the same weather as that at the base point, will decrease in proportion to the distance from the base point. In this sense, the areal extent of the high value of appearance probability with respect to snowy weather will mean the statistical width of the area of snowy weather around the base point.

Concerning the 88 station in Tohoku District (for station location see Fig. 2) the probability mentioned above are caluculated, making each station of them a base point, and then 88 maps representing the proabability distribution are obtained. From these maps it is known that the statistical width of snowy weather area varies with the base point taken.

As an example the map making Yonezawa (83 in Fig. 2) the base point are shown in Fig. 15, representing the probability distribution of the same weather appearance as in Yonezawa when Yonezawa is under the snowy weather. The characteristics, that the area showing high value elongates south to north, are commonly observed when the base point is in an inland region on the Japan

Fig. 15 Fig. 16

Fig. 15 Distribution of probability of snowy weather appearing at every station at the same time as in Yonezawa

Fig. 16 Probability distribution of coincidence degree with appeance of snowy weather in Yonezawa

Sea side. It suggests that snowy weather in the region tends to happen simultaneously. On the other hand, the simultaneous snowy area along the Japan Sea coast is narrowly localized, because the area of high value does not always extend widely when any base point is at the station along that coast.

2) Statistical center in snowy weather extent

The probability distribution in Fig. 15 calculated around Yonezawa as a base point, can be obtained only when Yonezawa is under snowy weather. Therefore the number of snowy days calculated at each station in this case is not the total number of all snowy days, but is counted excluding the days when it is not snowy in Yonezawa.

When Yonezawa is the base point, the probability at station n where snowy weather appears at the same time as in Yonezawa is

$$P_n = \frac{Y_n}{S_{83}} \times 100 \qquad (n = 1, 2, \cdots\cdots, 87, 88)$$

where S_{83} is the number of all snowy days in Yonezawa (83), and $Y_n(n=1, 2, \ldots, 87, 88)$ is the number of days when snowy weather appears at the station n when it snows in Yonezawa. The distribution snowing in Fig. 15 is of that P_n value. As this probability is calculated making the number of all snowy days the denominator, the distribution of the probability shows the pattern of the areal extension of snowy weather Yonezawa shows, from statistical view point. In other words, it means the areal pattern of coincidence degree with Yonezawa in regard to the snowy weather appearance.

From another point of view, the coincidence degree of a base point (here Yonezawa) with other stations concerning the snowy weather appearance can be obtained. The appearance probability of snowy weather in Yonezawa at the same time as at station n is

$$Q_n = \frac{Y_n}{S_n} \times 100 \qquad (n = 1, 2, \cdots\cdots, 87, 88)$$

where $Y_n(n=, 1, 2, \ldots 87, 88)$ is the number of snowy days in Yonezawa at the same time as at station n, and $S_n(n=1, 2, \ldots 87, 88)$ is the number of all snowy days at station n. Fig. 16 shows the distribution of Q_n value, which means the probability that the Yonezawa region can be included in the area of snowy weather appearing at station n. The values of Fig. 15 and Fig. 16 are largely different each other in the southern part of the District along the Pacific Ocean. The fact that the value is higher in Fig. 16 than Fig. 15 in that part of the District means that snowy weather does not always appear on the coastal area along the Ocean when it appears in Yonezawa, though it snows in Yonezawa in most cases when the former is under the snowy weather. And large difference in value between both figures means the marked tendency that the snowy area in and around Yonezawa seldom extends toward the Pacific coast, and that most of the snowy weather appearing in the coastal region is only in these sedlom cases. The tendency is most notable during mid-winter.

The proportion of such a tendency, in short, will be represented by the distribution of P_n-Q_n (here n=83) values. That is, the statistical center of the snow weather area extending to the base point will be known by the distribution pattern of the value in the area where $P_n - Q_n > 0$. The distribution of the

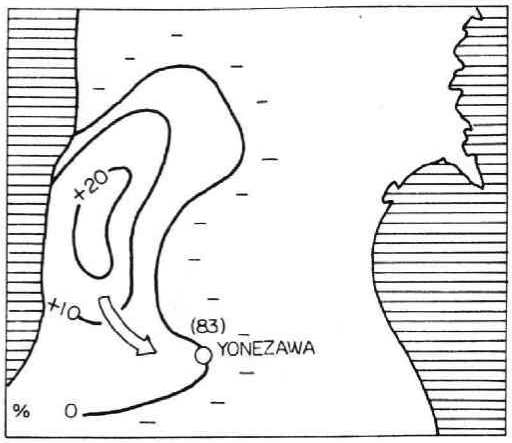


Fig. 17

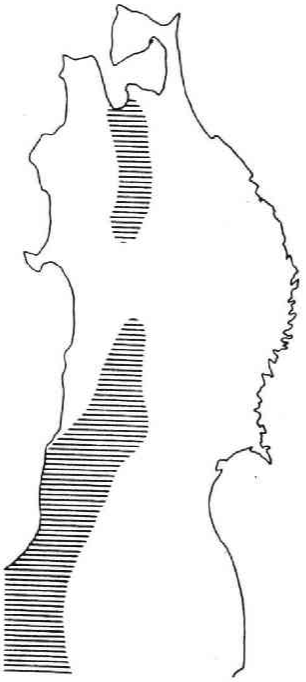


Fig. 18

Fig. 17 Central area of snowy weather appearance when it snows in Yonezawa
Fig. 18 Central area of frequency of snowy weather appearance in Tohoku District

P_{83}–Q_{83} (>0) is shown in Fig. 17, telling that the center in the weather area extending to Yonezawa is located on the western slope of the Echigo mountains.

By taking every 88 station as the base point, 88 sheets of maps have been drawn, which tell that the area of the maximum probability of the appearance of the center of snowy weather extent is located on the western or northwestern slope of the mountains fully exposed to W or NW wind, as shown in Fig. 18.

III Regional characteristics of weathr appearance

Based on the materials already mentioned above, the characteristics concerning the weather appearance are described according to each region. They are as follows:

1) The coastal region along the Japan Sea

The appearance frequency of fine weather is lowest in this region throughout Tohoku District. In the typical winter pressure pattern, fine weather can

hardly be expected, while snowy weather often appears. Many of the snowy weather appears as the extension from the western slope of the Echigo mountains in the southern part of the region, and of the Ou mountains in the northern part, though the extension does not always reach to the Japan Sea coast.

On the other hand, snowy weather peculiar to the coastal zone occasionally happens. Such a snowfall is called "Sato-Yuki (lowland snowfall), which is an antonym of "Yama-Yuki" (mountain snowfall), and in the former case it snows heavily in the coastal region, when the pressure gradient is very weak.

Snowy weather appearance in the coastal region is less frequent than in the inland region on the western side of the backbron range, while fine weather is the least because of too frequent cloudy weather.

2) The western slopes in Echigo mountains and in the northern part of the Ou mountains

These regions have highest frequency of snowy weather throughout Tohoku District. As these regions are fully exposed to the W-NW monsoon, snowy weather is frequently seen in every flow-pattern in the winter type pressure pattern. Cloudy weather is not so frequent that the number of fine days in the slopes is larger than in the Japan Sea coast. In these slopes, it snows always when it snows anywhere in the western side of the backbone range, because almost all of the snowing in this side appears as the extension of the snowing in each of the slopes. In this sense, both slopes form the original areas of snowy weather in Tohoku District.

3) The group of basins in the western side of the backbone range

The apparance frequency of every kind of weather varies with basins, because the topographical conditions of each basin is different each other. In the diagram showing the combination of the frequencies of three kinds of weather, the dots representing stations in the basins spread over A, B and C groups (Fig. 13). An area with more frequent snow lies covering the basins of Yonezawa (g in Fig. 2), Shinjo (d) and Inawashiro (i) and in the Aomori (11) region, and less frequent ones in the basins of Yamagata (f), Aizu (h) and Hirosaki (a). Such a tendency is noticeable in the typical winter-pattern pressure distribution.

The cloudy or snowy weather of the Japan Sea coast tends to spread over the Hirosaki basin and seldom spreads to the basins of Yamagata, Yonezawa and Aizu. Anyway it is frequently snowy and seldom fine in the basins of Shinjo and Obanazawa (e) and in the Aomori region, and in both the basins of Yokote (c) and Yonezawa only in the winter-type pressure pattern. It is less snowy and more fine in both the basins of Yamagata (Fig. 19) and Aizu.

The characteristics of weather appearance frequency of these basins are different

each other, becasue the kind of flow-pattern, under which the basin floor is sheltered by surrounding mountains, is different basin by basin influenced by the relief of the mountains, and because the appearance of the flow-pattern is different according to the kind of the pattern.

Generally speaking, however, snowy weather in the Aomori region and the basins of Odate and Hirosaki, appears mostly as the extension from the western slope of the Ou mountains, while the weather in the basins south of the Yokokte basin, from the slope of the Echigo mountains.

4) Inland regions on the eastern side of the backbone range

In these regions, on the leeside of the backbone range, snowy or cloudy weather with wide extension is rarely seen in mid-winter, because the backbone range interrupts the eastward extension of the weather. They have more of fine weather than the opposite side of the range.

Since the shelter-effect by the backbore range does not work at the lowered saddles in the backborn range, snowy or cloudy weather on the western side extends occasionally eastward through the parts. The regions at such a location are the region around Okunakayama(18), the regions of Hanamaki (28) and Mizusawa (29), Sempoku plain (k) (Fig. 19 II) the Fukushima basin (1), and the Koriyama basin (m). Fig 20 shows the frequency distribution of snowy weather appearance, which is characterized by the pattern that snowy weather is comparatively frequent in these region when the weather is seen in any place (here Fukushima) leeward of the saddle-like part.

Four of these regions, Hanamaki, Okunakayama, Sempoku and Koriyama to the east of the saddle, have high appearance frequency of cloudy or snowy weather

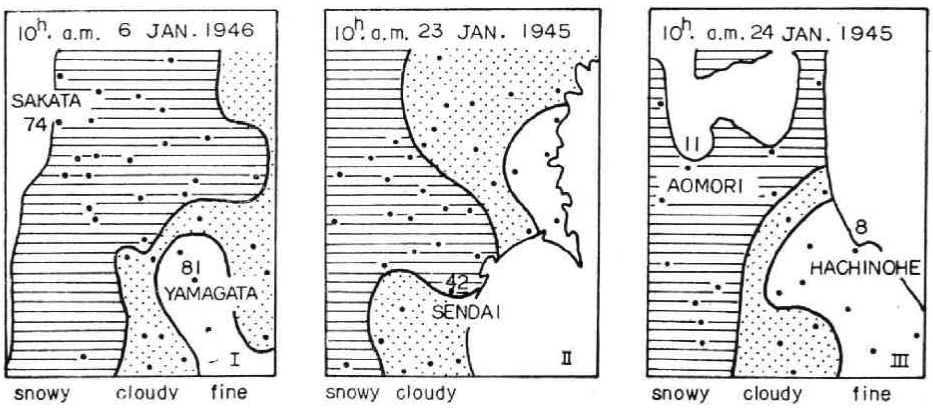


Fig. 19 Examples of weather distribution in mid-winter

in the case of the W flow-pattern, and two of these (Mizusawa and Fukushima) to the southeast of the saddle in the case of the WNW flow-pattern.

In the northern part of the Sambongi plain (j), on the other hand, the same weather as in the Japan Sea side frequently appears with high frequency for NW-W flow-pattern, because the part has no shelter mountain against the N or NW wind. An example of weather pattern thereof is shown in Fig. 19, III, and the frequent

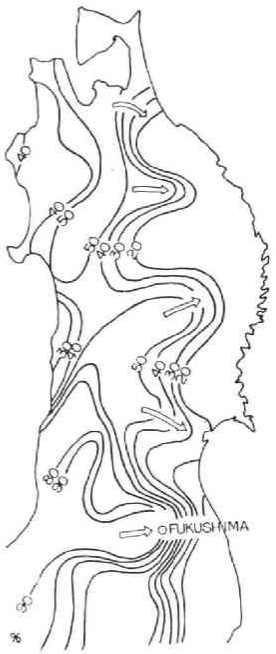


Fig. 20

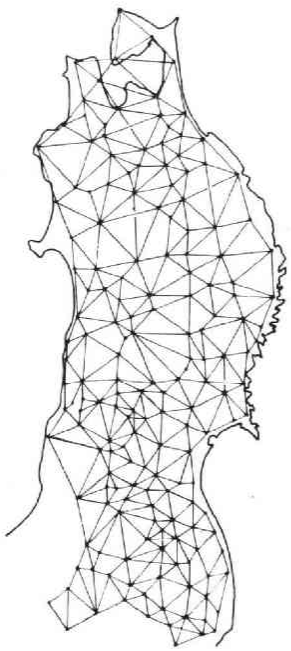


Fig. 21

Fig. 20 Probability distribution of snowy weather appearance when it is snowy in Fukushima

Fig. 21 Weather observation stations linked by each segment of line

appearance of similar pattern will be understood by Fig. 3, Fig. 4, Fig. 7, Fig. 8 and Fig. 15. As the appearance of cloudy or snowy weather in the middle part of the plain is the extension from the north, the frequency of the weather is comparatively high when the flow-pattern has N-component.

5) Coastal region along the Pacific Ocean

In this region winter weather is fine in most cases except in the northern part of Sambongi plain, and snowy weather is rarely seen so far as the NW or W monsoon prevails.

IV. Statistical divide between the different weather areas

In the weather distribution pattern, the divide ought to lie between two areas with different weather. In winter the divide tends to be concentrated on certain location in Tohoku District. However, the divide can not be drawn correctly in a map, because the existence of the divide can be known only by the fact that weather at one station is different from that at its adjacent station. In this case, the undoubted fact is that the divide crosses a segment of straight line linking these stations. In order to obtain regionally the appearance frequency of the divide, the following method is adopted;

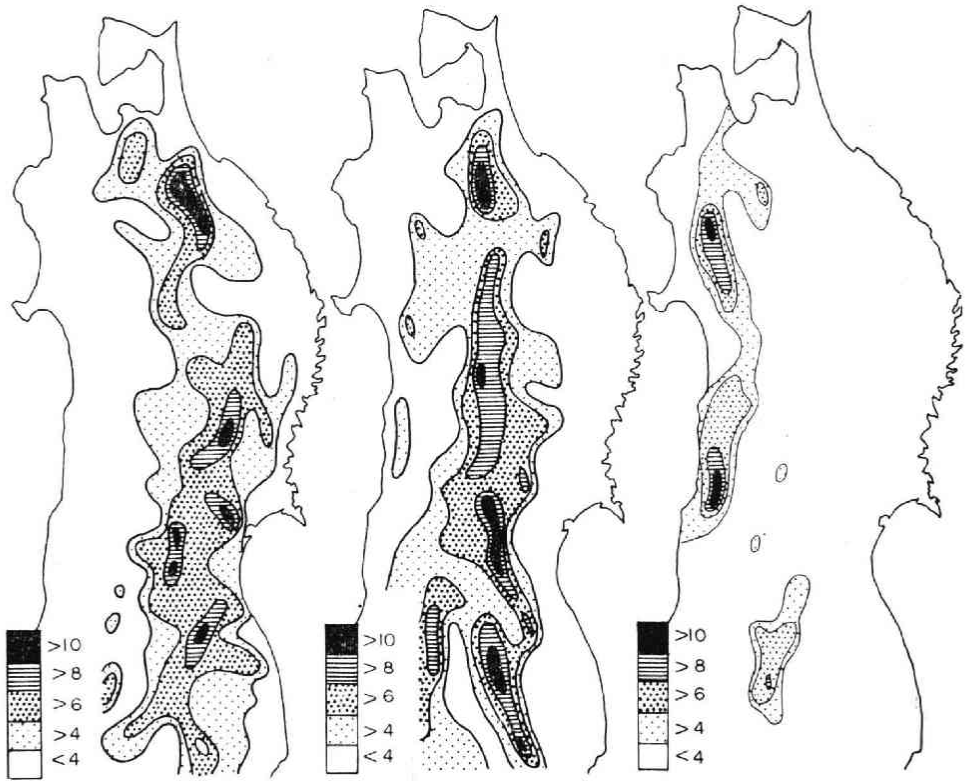


Fig. 22 Fig. 23 Fig. 24

Fig. 22. Density distribution of the weather divide showing the eastern limit of cloudy weather

Fig. 23. Density distribution of the weather divide showing the eastern limit snowy weather

Fig. 24. Density distribution of the weather divide showing the western limit of snowy weather

i) Stations adjacent each other are linked with segments of straight line in a map (Fig. 21), ii) Frequencies in which the divides cross the lines in mid-winter are counted in every line. iii) The obtained values are reduced to unit distance (here, 10 k.m.), and these numerical figures are written at the middle point of each line. iv) In this way distribution maps showing the frequency of the weather divide can be drawn.

Fig. 22 is a map with respect to the divide between cloudy weather on the southern side and fine weather on the eastern side, that is, the map of density distribution with respect to the eastern limit of the cloudy weather area, and Fig. 23, to eastern limit of the snowy weather area.

Since snowy weather appears more frequently in the inland region on the Japan Sea side than in the region along the Japan Sea coast as already mentioned, the divide between these regions accordingly run from south to north parallel to the coast. The density distribution of the divide as the western limit of the snowy area is shown in Fig. 24. The axis of the maximum density in these distribution maps can be called the areal boundary from the statistical view-point with respect to weather appearance.

V Regional division from the view-point of the characteristics of mid-winter weather.

From what was mentioned above, the regional characteristics of weather appearance in Tohoku District can be summarized as follows:

J ***Weather type of the Japan Sea side***

Snowy or cloudy weather is comparatively frequent

Jc Weather type of the Japan Sea coast

Occasional snowy or cloudy weather, limited to the coast of the Japan Sea, and ordinary snowy weather extended from Jm, very seldom fine weather, frequent cloudy weather

Jm Weather type of the western slope of the mountains

Very frequent snowy weather, centers of snowy weather area in Tohoku District

Ji Weather type of the basin group on the Japan Sea side (is divided into the following two subtypes)

Ji–1 Transitional type between Jm and Jc

Ji–2 Transitional type betwen Ji–1 and the type of the Pacific side (**P**), more frequent fine wether on the west side of the backbone range

P ***Weather type of the Pacific side***

Comparatively frequent fine weather and seldom snowy weather

Pi Weather type of inland on the Pacific side
Seldom snowy weather, sometimes cloudy

Pj Weather type of neutral region between both sides of backbone range
Similar to Pi, occasional expansion of snowy or cloudy weather from the Japan Sea side at the hard blowing of the monsoon

Pc Weather type of the Pacific Ocean coast
Frequent fine weather, seldom snowfall

Fig. 25 shows the distribution of these weather types.

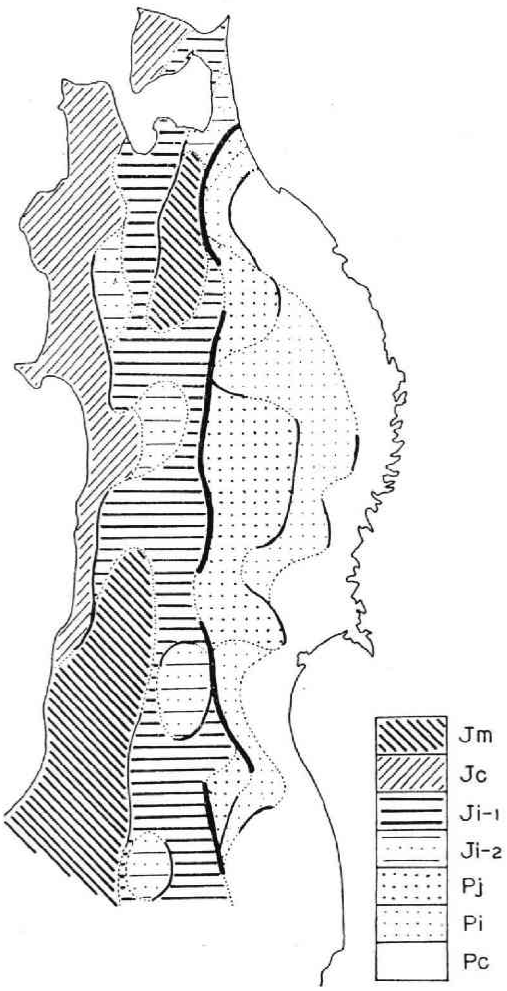


Fig. 25 Regional division viewed from weather appearance in mid-winter in Tohoku District

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